Oscilloscopes Are More than Just a Digital Instrument

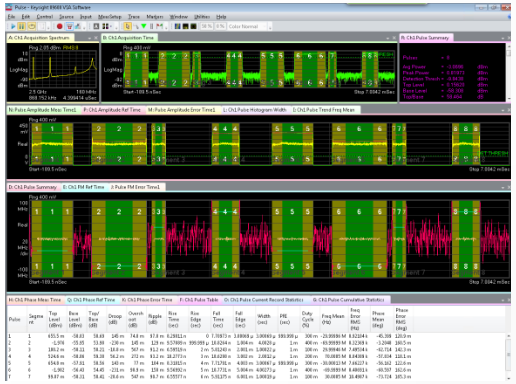
APRIL 2019

KEYSIGHT TECHNOLOGIES

Agenda

- Wideband RF challenges **(5 min)**
- RF Measurements using an oscilloscope **(30 min)**
  - When to use an Oscilloscope vs Spectrum Analyzer?
  - What RF measurement capability is available in a scope?
  - Basic FFT example (with 1 GHz sine wave input)
  - FFT to reveal a noise source on power supply rail
  - Gated FFT and waveform math to analyze RF pulses
  - Determining RF measurement quality with a scope

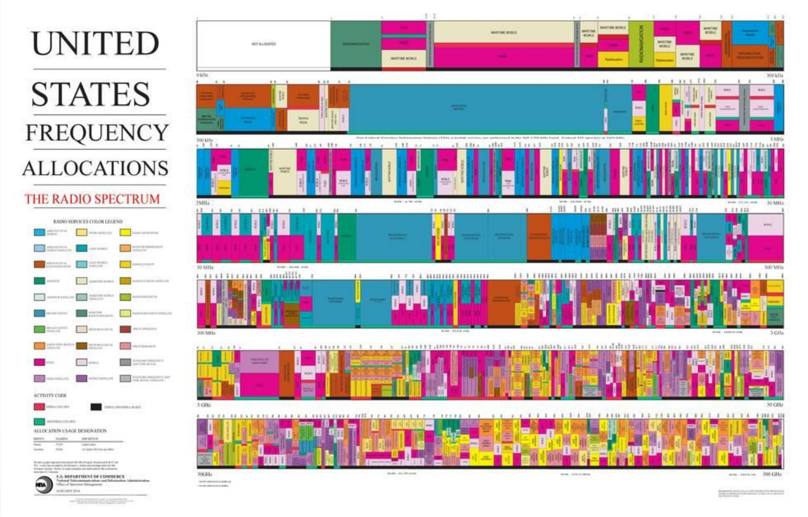
- Complimenting the Scope with additional RF analysis software **(15 min)**
  - Added RF measurement capabilities
  - Pulsed RF and QAM16 examples



Opening Up Spectrum

NEAR TERM

The FCC is facing pressure to speed up the process for auctioning off 5G-critical spectrum. Carriers plan to use the new spectrum to build out ultra-fast networks that will power the internet of things, autonomous vehicles, and other emerging technologies. Telecom companies and policymakers have urged the FCC to move more quickly to repurpose the spectrum.



Frequency Band	Auction Year
1300-1350 MHz	2024
3.7 GHz – 4.2 GHz	2019
24 GHz (24.75-25.25)	2018-2019
28 GHz (27.5-28.35)	2018
37 GHz (37-38.6)	2019
39 GHz (38.6-40)	2019
47 GHz (47.2-48.2)	2019

KEYSIGHT TECHNOLOGIES

*FCC NPRM – "Use of Spectrum Bands Above 24 GHz For Mobile Radio Services"; October 2017

Opening Up Spectrum

NEAR TERM

***GOAL:** Make available millimeter wave (mmW) spectrum, at or above 24 GHz, for fifth-generation (5G) wireless, Internet of Things, and other advanced spectrum-based services.*

24.75-25.25 GHz – allow for more flexible FSS (fixed-satellite service)

48.2-50.2 GHz - looking to authorize fixed and mobile operations in this band as well a sharing

57-64 GHz - maintain unlicensed use of the band, also allow unlicensed use during aircraft flight

64-71 GHz – maintain unlicensed use of the band, also allow unlicensed use during aircraft flight

70 GHz (71-76 GHz) – focus bands on fixed and other newer and innovative uses

80 GHz (81-86 GHz) – focus bands on fixed and other newer and innovative uses

90 GHz (92-95 GHz) - focus bands on fixed and other newer and innovative uses

*FCC NPRM – "Use of Spectrum Bands Above 24 GHz For Mobile Radio Services"; October 2017

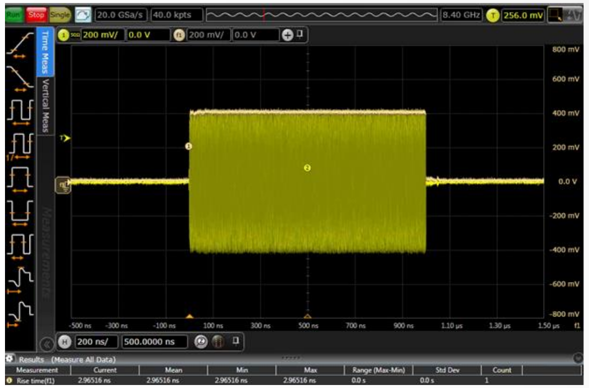
Wideband RF challenges for customers

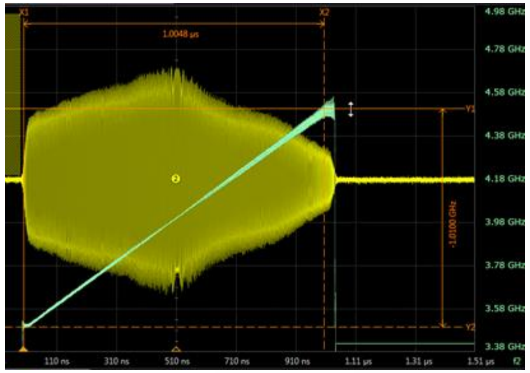
- Many RF designs > 2 GHz wide
- Difficult to use real-time vector signal analyzers at wide width
- Pulsed RF signals often have low duty cycle so difficult to capture long target time
- Is a need for wideband RF receivers with accurate amplitude and phase response

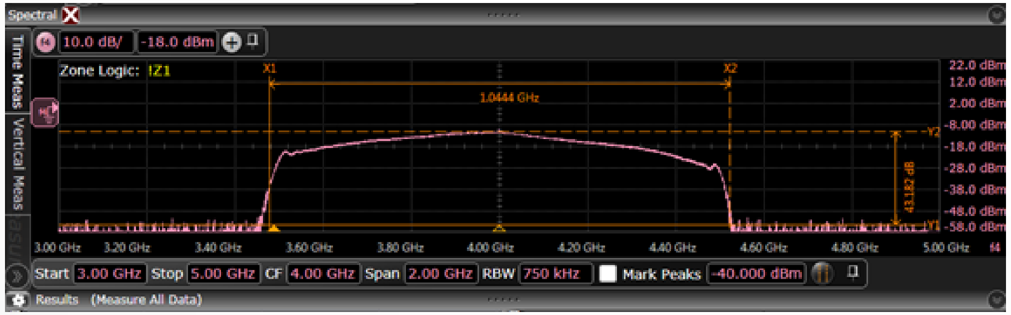
Modern radar /EW systems are often characterized by wide spectral width

Common Wideband Pulsed RF Measurements Required

- Pulse width, rise time, fall time on envelope
- Frequency shift across pulse
- Phase shift across pulse
- PRI
- Spectral width, spectral characteristics
- Pulse characteristics over a long period (10 seconds)





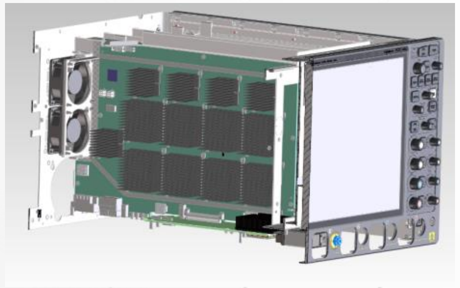


KEYSIGHT TECHNOLOGIES

Meet the Infiniium UXR-Series

MORE ACCURATE ANALYSIS - RUNS FASTER - FULLY UPGRADABLE

Fully upgradable modular design



- Models from **13 GHz to 110 GHz** of real-time bandwidth
- 2 or 4 channels per scope - **ALL** with **FULL** rated bandwidth
- Best in class sample rates:
  - 13 – 33 GHz models: 128 GSa/s per channel
  - 40 – 110 GHz models: 256 GSa/s per channel
- 200 Mpts/ch standard – Upgradable to 2 Gpts per channel
- **High-Definition 10-bit Analog-to-Digital Converter (ADC)**
- Best signal integrity and vertical resolution
- **Hardware based acceleration ASICs**
- Optional self calibration module – enables you to perform a factory quality frame calibration at your location

KEYSIGHT TECHNOLOGIES

Preliminary Banner Specifications

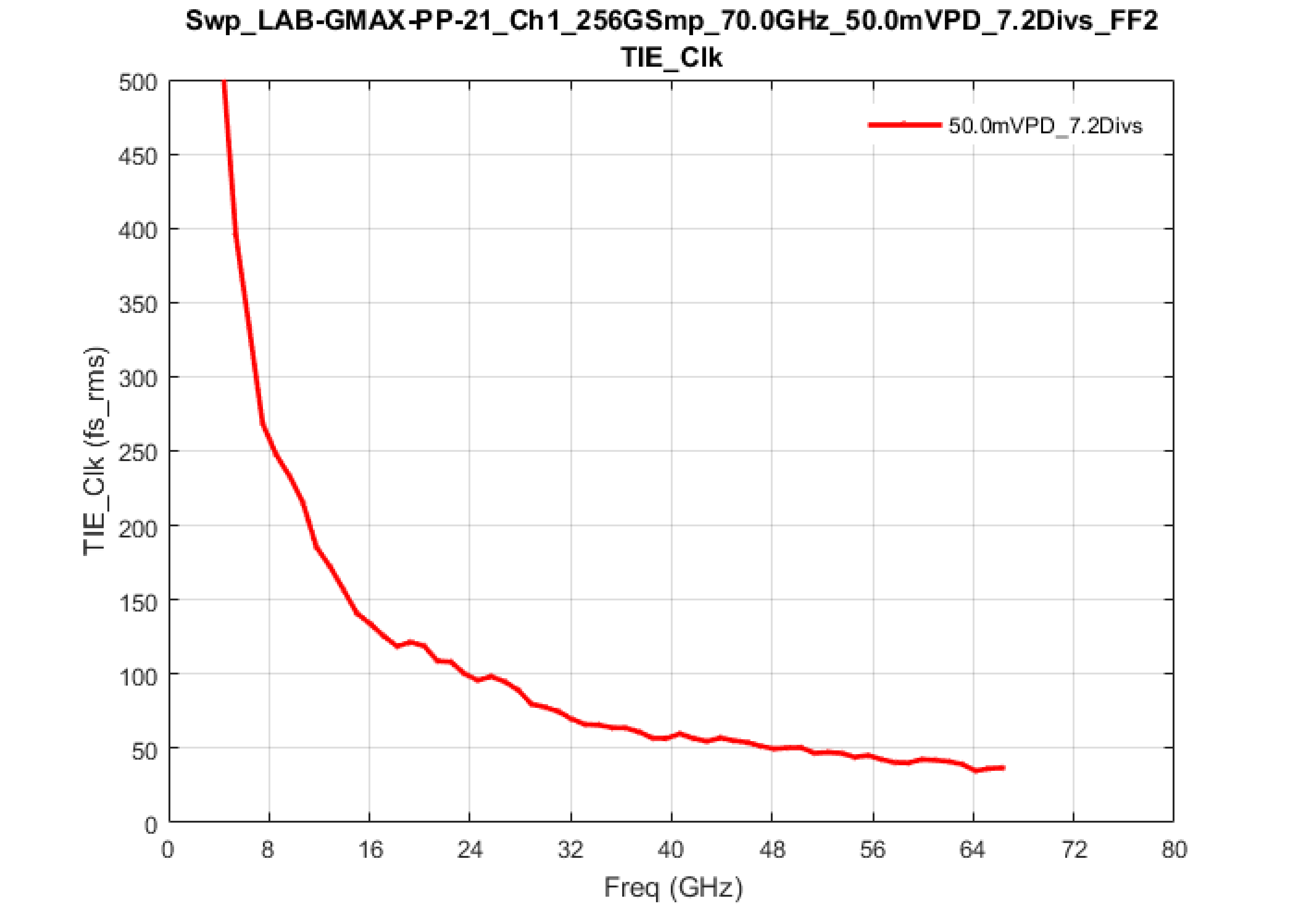
BEST SIGNAL INTEGRITY ACROSS ALL BANDWIDTHS

Specs (At Max Bandwidth)	1 mm Models	1.85 mm Models	3.5 mm Models
Bandwidth	59 to 110 GHz	40 to 70 GHz	13 to 33 GHz
Sample Rate	256 GSa/s per channel	256 GSa/s per channel	128 GSa/s per channel
Noise (Highest sensitivity)	< 0.9 mV (rms)	< 0.5 mV (rms)	< 0.3 mV (rms)
Intrinsic Jitter	20 fs (rms)	20 fs (rms)	20 fs (rms)
Inter-Channel Jitter	10 fs (rms)	10 fs (rms)	10 fs (rms)
ENOB	> 5.0 bits (100 GHz)	> 5.4 Bits (70 GHz)	> 5.9 Bits (33 GHz)
Vertical sensitivity (HW) Vertical sensitivity (w/ zoom)	60 mV to 4 V Full scale 1 mV/div to 500 mV/div	60 mV to 4 V Full scale 1 mV/div to 500 mV/div	40 mV to 8 V Full scale 1 mV/div to 1 V/div

KEYSIGHT TECHNOLOGIES

Measured TIE less than 50fs on 70GHz measurement.

INTRINSIC + RANDOM (NOISE) JITTER



Spec:
50mVpd,70GHz = 2.2mVrms noise.
Slew rate = 90% *200mV * 2pi * 70GHz.
Jitter due to noise = noise / slewrate = 28fs
Sqrt (28fs^2+25fs^2) = 37fs rms.

Very close to measured value.

Spec is 5x rms value.

Some time and frequency domain translation

When you say…	Time hears…	Frequency hears…
Bandwidth	DC to a BW	Bandwidth around a center frequency
Wideband	1GHz or more	10MHz or more
DC	DC (like a battery)	Anything less than 9KHz
Channel	Connector on front of instrument	Communication medium
Port	Simulation term	Connector on front of instrument
Decimate	Downsample	Filter and then downsample
Realtime	>Nyquist max sample rate. Post processing OK.	Gap free processing.
50 Ohm termination	50 Ohms to ground- or (for BERTs and some probes) to a Vterm.	50 Ohms AC coupled.

Using an oscilloscope in today's RF/Wireless Markets

PROS AND CONS

- Pros
  - Very wide BW.
  - Very good in-band performance (EVM).
  - Very good multi-channel coherency.
    - 4 channels in one scope.
    - Future >4 channel capability (Multiscope).
    - Separate CF per channel, maintains coherency.
  - Preamp and attenuator per channel
    - +16dBm to -20dBm full scale
  - Expandable to 4 channels.
  - Expandable to 110GHz.

- Cons
  - Limited out-of-band performance (spur limited).
  - Speed (until DDC).
  - Price (until mmWave Extension).
  - Limited hard specifications

Addressing Three Biggest CONs

UNDERSTANDING THE PROBLEMS

Price	Speed	RF measurements
• Scopes are expensive compared to analyzers	• Scopes are slow in their RF modes • Measurements that take second on an analyzer take mintues on the scope	• How good is the scope in non-normal scope measurements? • DANL, TOI, SFDR, EVM, et cetera

Phase Coherency

INTER-CHANNEL JITTER (SEE DATASHEET PAGE 48)

Inter-channel no averaging

$$\pm\left[5\cdot\sqrt{\begin{pmatrix}\text{Time Interval}\\\text{Error (Edge1)}\end{pmatrix}^2+\begin{pmatrix}\text{Time Interval}\\\text{Error (Edge2)}\end{pmatrix}^2+\begin{pmatrix}\text{Inter channel}\\\text{Intrinsic Jitter}\end{pmatrix}^2}+\left(\begin{pmatrix}\text{TimeScale}\\\text{Accuracy}\end{pmatrix}\cdot\begin{pmatrix}\text{Delta}\\\text{Time}\end{pmatrix}\right)+\begin{pmatrix}\text{Interchannel}\\\text{Skew Drift}\end{pmatrix}\right]$$

Inter-channel 256 averages

$$\pm\left[\frac{5}{16}\cdot\sqrt{\begin{pmatrix}\text{Time Interval}\\\text{Error (Edge1)}\end{pmatrix}^2+\begin{pmatrix}\text{Time Interval}\\\text{Error (Edge2)}\end{pmatrix}^2+\begin{pmatrix}\text{Interchannel}\\\text{Intrinsic Jitter}\end{pmatrix}^2}+\left(\begin{pmatrix}\text{TimeScale}\\\text{Accuracy}\end{pmatrix}\cdot\begin{pmatrix}\text{Delta}\\\text{Time}\end{pmatrix}\right)+\begin{pmatrix}\text{Interchannel}\\\text{Skew Drift}\end{pmatrix}\right]$$

Inherent inter channel jitter <***10fs rms*** (not-measureable)

Jitter from one channel @39GHz, 1GHz BW. (not – can be removed with averaging).

- Assume 800mV p-p (400mV o-p) sin wave @ 39GHz = 9.8E10 V/s slew rate at zero crossing.
- 3.7mVrms noise /sqrt(50GHz/1GHz) = 523uVrms noise
- Vrms noise / slew rate = Rj of channel = 5.3fs rms. Sqrt(5.3fs^2+25fs^2) = 25.5fs rms TIE E1/E2
- Assume delta time ~=0.
- Assume Inter-channel skew drift =0 (recent adjust/calibrate, stable tempertature)

No averaging (max error): 5* sqrt(10fs^2+2*25.5fs^2) = 187fs ~= +/-2.5deg @ 39GHz.

Averaging can drive to zero. Reduce rms part by sqrt (num averages).

5dC change can drive 1ps drift (14 degrees)

PRICE

The Scope Price Dilemma for mmWave Applications

CUSTOMER BUDGETS LIMIT ADOPTION OF HIGH BW SCOPE OPTIONS

- On a typical scope to digitize RF communications up to 70 GHz, customers need to have all 70 GHz running at once
  - The cost is well above $650K
- If a customer wants to look above 70 GHz, they are looking at needing budgets in excess of $1M
- Many RF applications only need to see inside a particular frequency band < 5 to 10 GHz wide
- This is a lot of extra $$$ for bandwidth that isn't needed
- Customers would prefer to pay for only the GHz they need
- Mixers / down conversion is a viable option for RF applications to address the testing requirements
  - Results in a palatable loss in signal fidelity, but is justified in $$$ savings

New ways to purchase scopes

HOW IT WORKS

Buy one of the 1 mm input UXR scope models

25, 40, 59, 70, 80 or 100 GHz

Then, buy the 5 GHz or 10 GHz mmW extension option

This gives flexible banded support all the way to 110 GHz

Instead of paying over $1M for a 110 GHz scope, pay for only the bandwidth needed and look at only the frequency bands needed to up to 110 GHz

Plus, get a full mmWave capable scope to use to at any BW

i.e. ≤ 25 GHz for $300K

Typical configured price: 25 GHz scope, 5GHz mmWave extension (any 5 GHz band to 110 GHz), 2GSa memory option (~8ms capture time), VSA SW … ~$450K

Setting up mmWave Extension in the UXR

From the Setup menu, choose the Signal Type… submenu

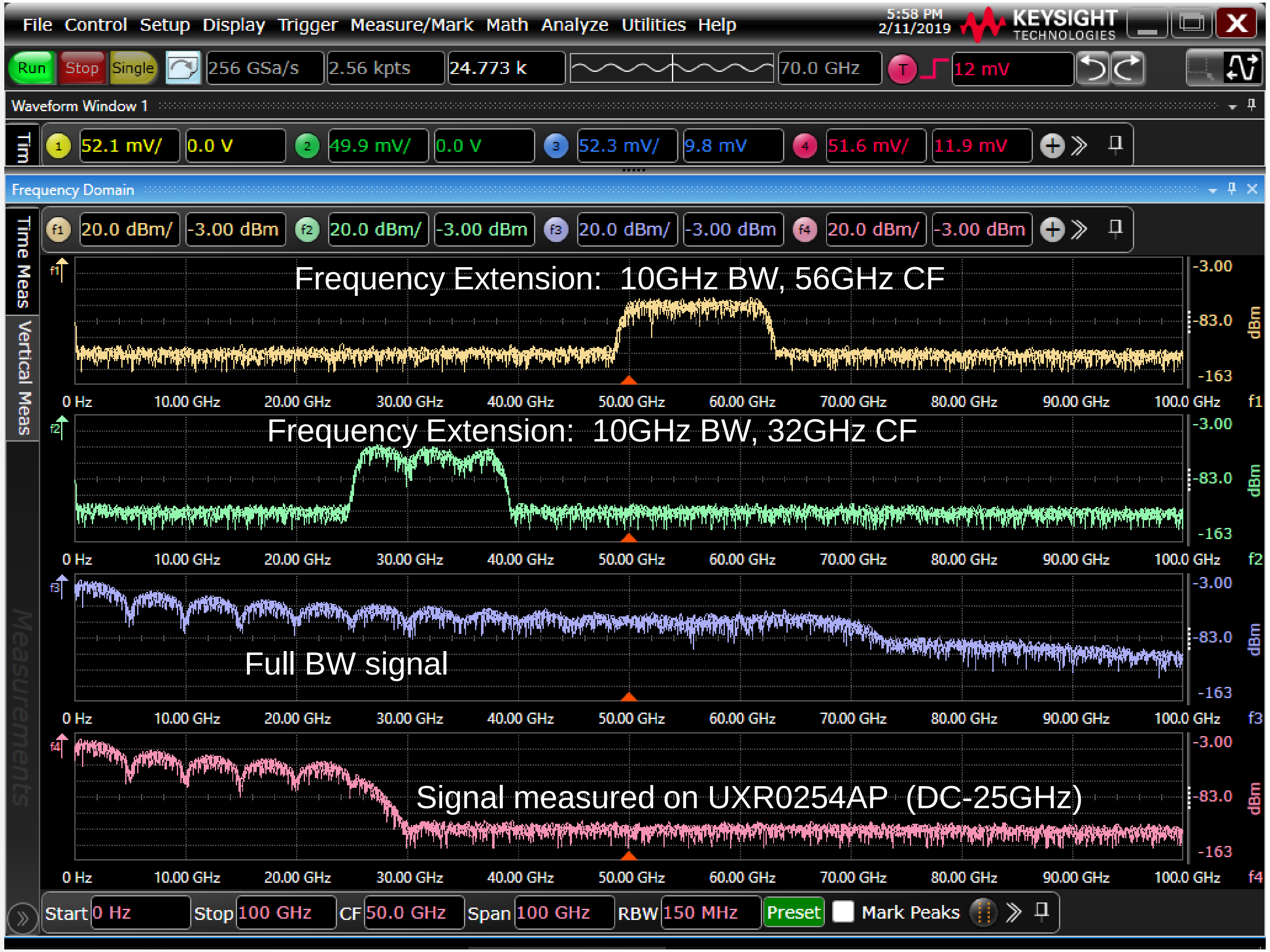
From the Signal Type dialog, choose the Frequency Extension Signal type for your mmWave Channels.

Measurement BW will be set by which mmWave extension you have purchased (5 or 10GHz).

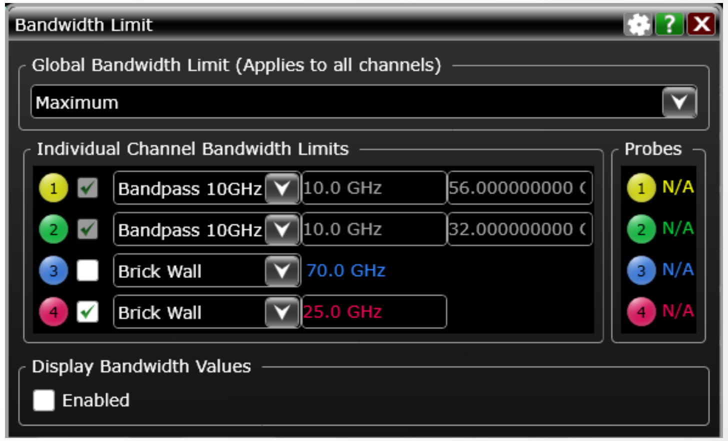
Set the Center Frequency of your mmWave signal. Up to 110GHz with 1mmHW models.

Using the mmWave Extension in the UXR

Ultra wide BW signal into all 4 channels of UXR (FFTs 100GHz span).



- Buy a mmWave Frequency Extension.
  - Buy 5 or 10GHz BW.
  - Use to 110GHz on 1mm UXRs.
  - Use to 70GHz on 1.85mm UXR.
- Buy a 2 or 4 channel scope.
  - ***Each channel can be Baseband or mmWave signal type.***
  - ***Each mmWave channel can have a different center frequency.***
- Fully upgradeable.
  - Upgrade 2->4 channels
  - Upgrade 5GHz -> 10GHz mmWave Extension
  - Upgrade scope BW to 110GHz



See all BWs set in “Bandwidth Limit” Dialog.

SPEED

Speed vs. Performance Tradeoff in 5GNR EVM

TODAY

Capture…

Process…

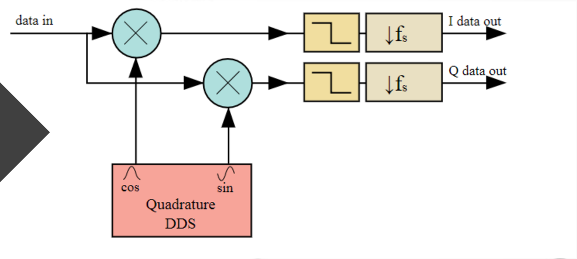
Best performance 256GSa/s

Or

Lower sample rates

Memory

Then post process in VSA SW

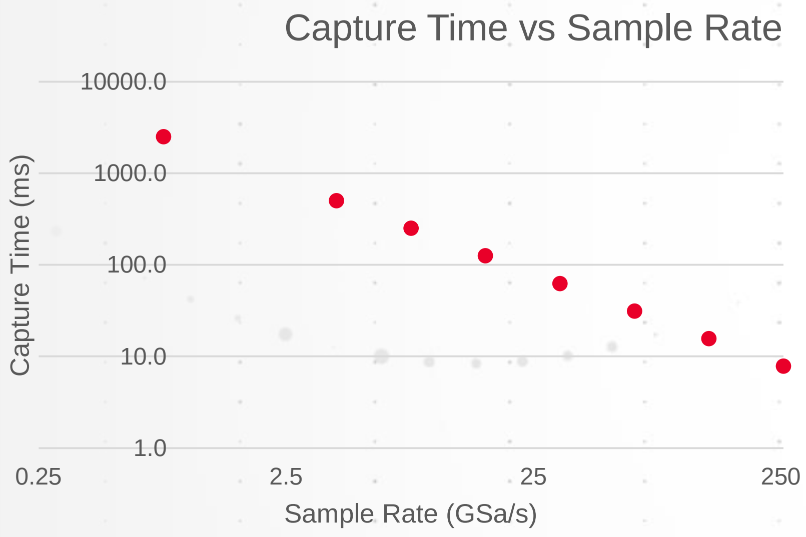


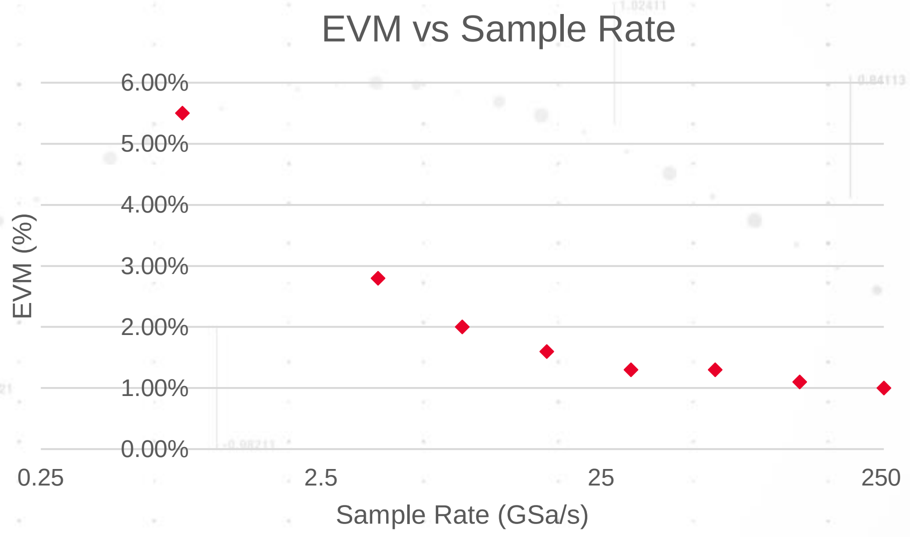
Lower sample rates are simply down-sampled.

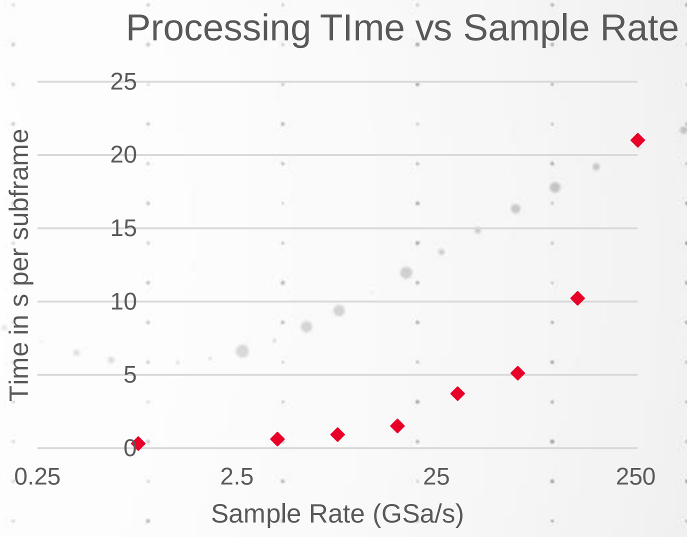
- No real-time filtering.
- -3dB SNR for each ½ SR (aliased noise).
- Other signals may alias.
- Signal must not cross between Nyquist zones.
- Maximum capture time increases with lower sample rates.
- Processing speed increases with lower sample rates.

Speed vs. Performance Tradeoff in 5GNR EVM

BEFORE DDC AVAILABLE



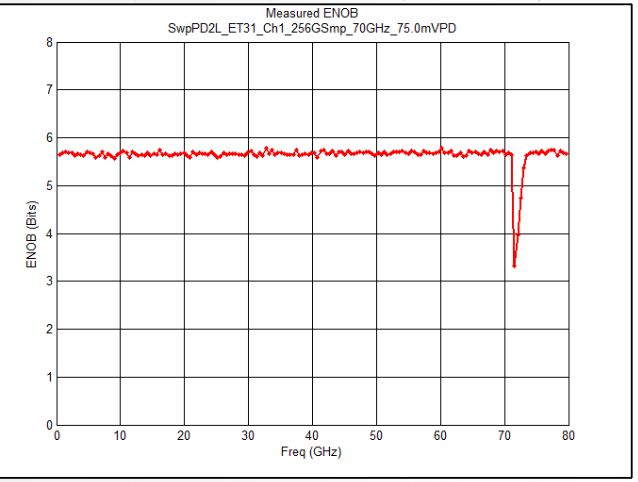


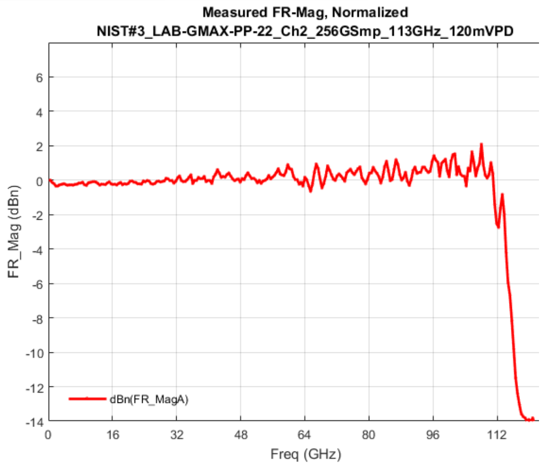


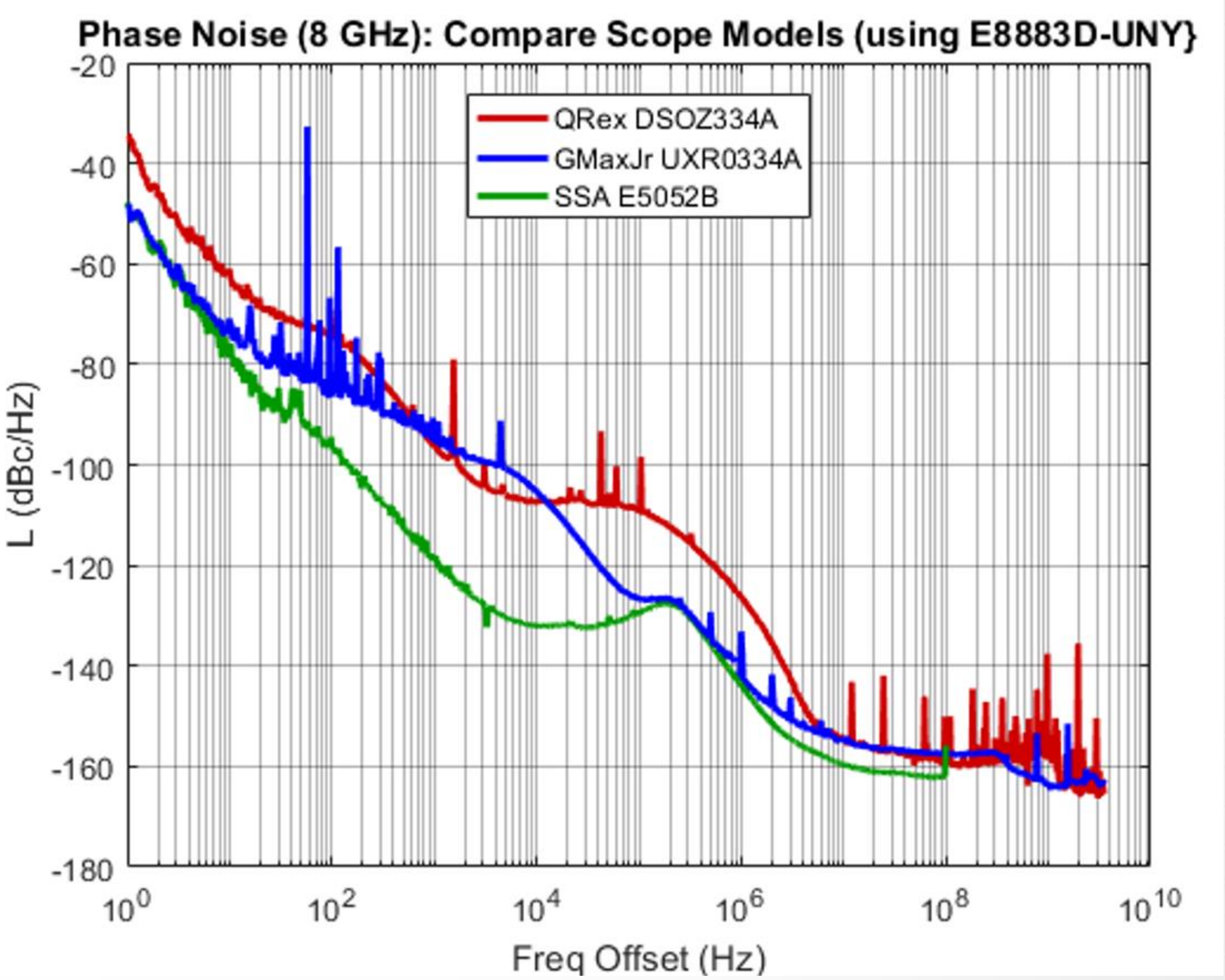
RF MEASUREMENT PERFORMANCE

New scope performance

SCOPES CONTINUE TO GET BETTER IN THEIR RF PERFORMANCE







Models	UXR0502A
Range - full scale -dBm	noise density - dBm/Hz
-20.5	-161.7
-16.0	-159.0
-11.9	-155.7
-4.0	-148.9
2.0	-142.6
8.1	-136.5
16.0	-128.9

UXA and UXR – Comparison of mmWave Capabilities

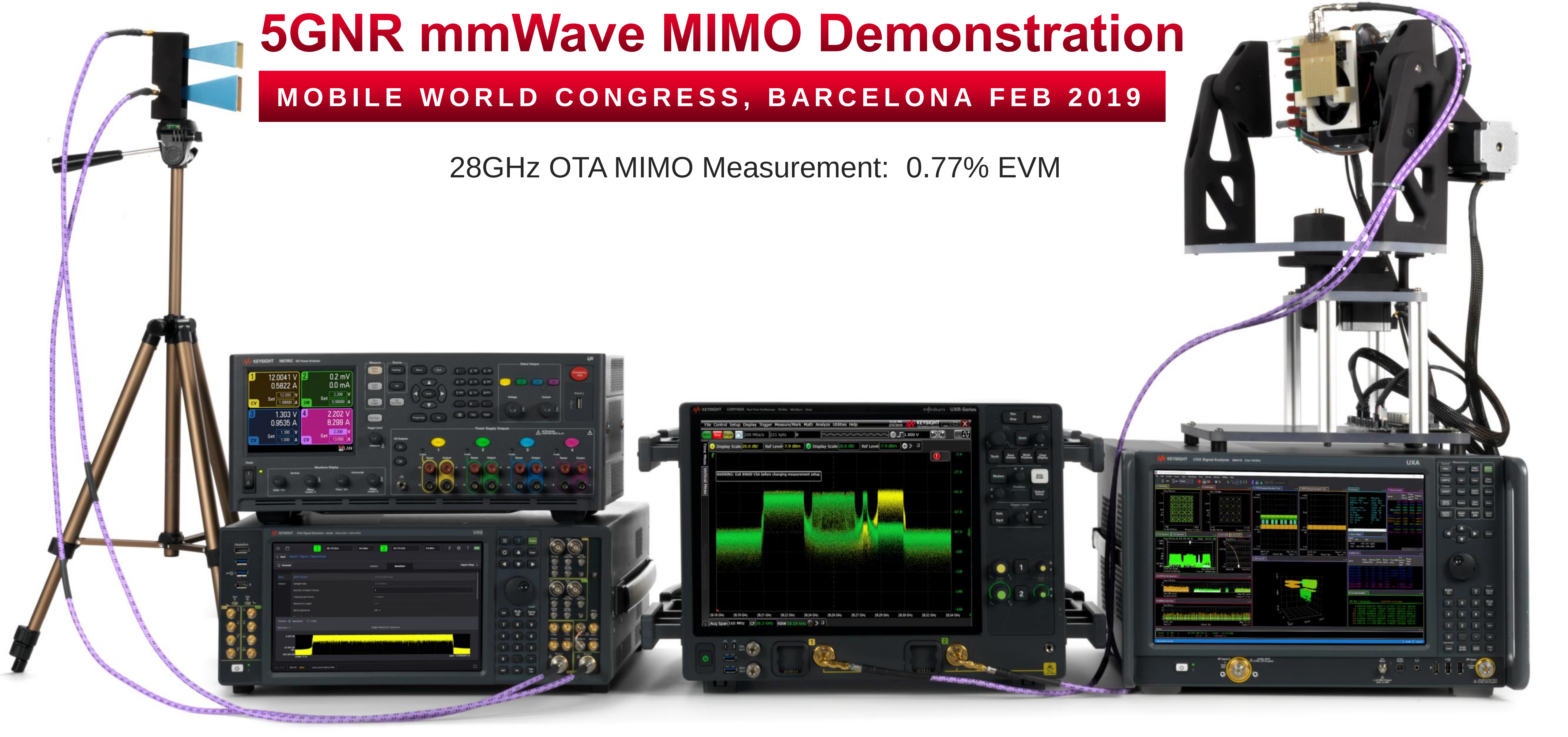
BEST IN CLASS INSTRUMENTS FROM KEYSIGHT

	UXR	UXA
Instrument Type	Infiniium Realtime Oscilloscope **Wide time domain application support**	X-Series Spectrum Analyzer **Wide frequency domain application support**
89601B Vector Signal Analyzer SW Support	Full support, including multichannel measurements and segmented capture	Full support, including segmented capture
Maximum Frequency Range	DC-110GHz	2Hz-110GHz
Maximum Analysis Bandwidth	**110GHz** (100GHz with VSA SW)	1GHz (5GHz @ >50GHz CF with external oscilloscope)
Maximum # Channels	**4** (20 with Multi-scope, 4 with VSA SW)	1
Noise Floor (DANL)	**Measured, -16dBm range** **25GHz: -159dBm/Hz** **50GHz: - 157dBm/Hz** **75GHz: -156dBm/Hz** Specified NA	Measured, -16dBm range 25GHz: -145dBm/Hz 50GHz: - 135dBm/Hz 75GHz: -148dBm/Hz Dave E. Please review. **Specified** **1GHz: -174dBm/Hz** **With Noise Floor Extension**
TOI	Measured, 6dBm range 3.65GHz: +22dBm 26.5GHz: +18dBm 50GHz: +11dBm Specified NA	**Measured, 6dBm range** **3.65GHz: +25dBm** **26.5GHz: +25dBm** **50GHz: +23dBm** **Specified** **1GHz: +20dBm**
Phase Noise @ 1GHz	10KHz offset: -124dBc/Hz measured 100KHz offset: -143dBc/Hz measured MikeB to review.	10KHz offset: -135dBc/Hz nominal 100KHz offset: -139dBc/Hz nominal
Multi-Channel Phase Coherence	**Inter-channel jitter @39GHz, 1GHz BW: +/-2.5deg (0.5deg rms)**	NA
Real-time Spectrum Analysis (RTSA)	NA	**Up to 255MHz**
Residual EVM (100MHz 5GNR, 39GHz)	**0.8% (measured)**	**0.7% (measured)**

5GNR mmWave MIMO Demonstration

MOBILE WORLD CONGRESS, BARCELONA FEB 2019

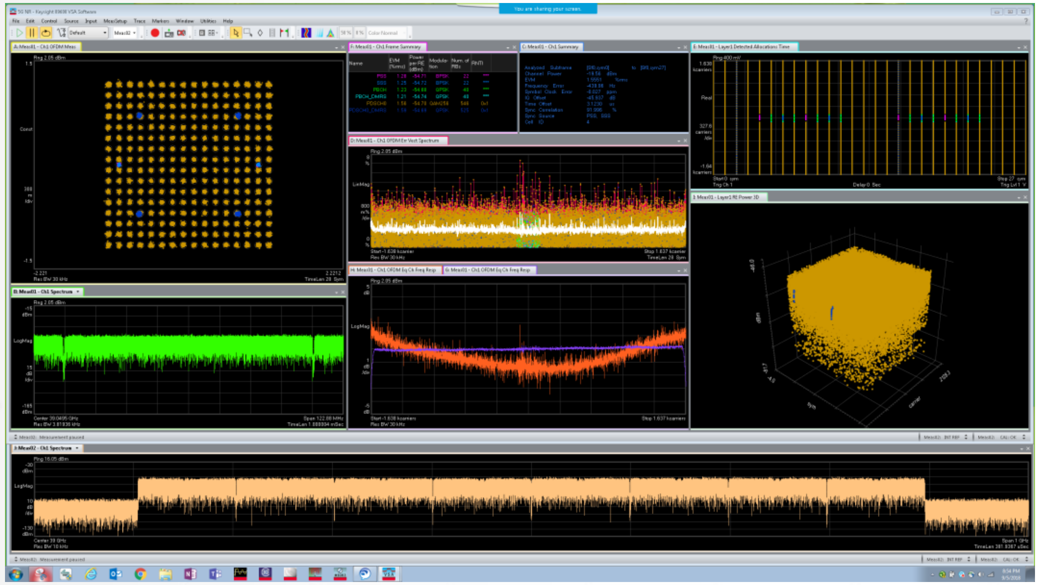
28GHz OTA MIMO Measurement: 0.77% EVM

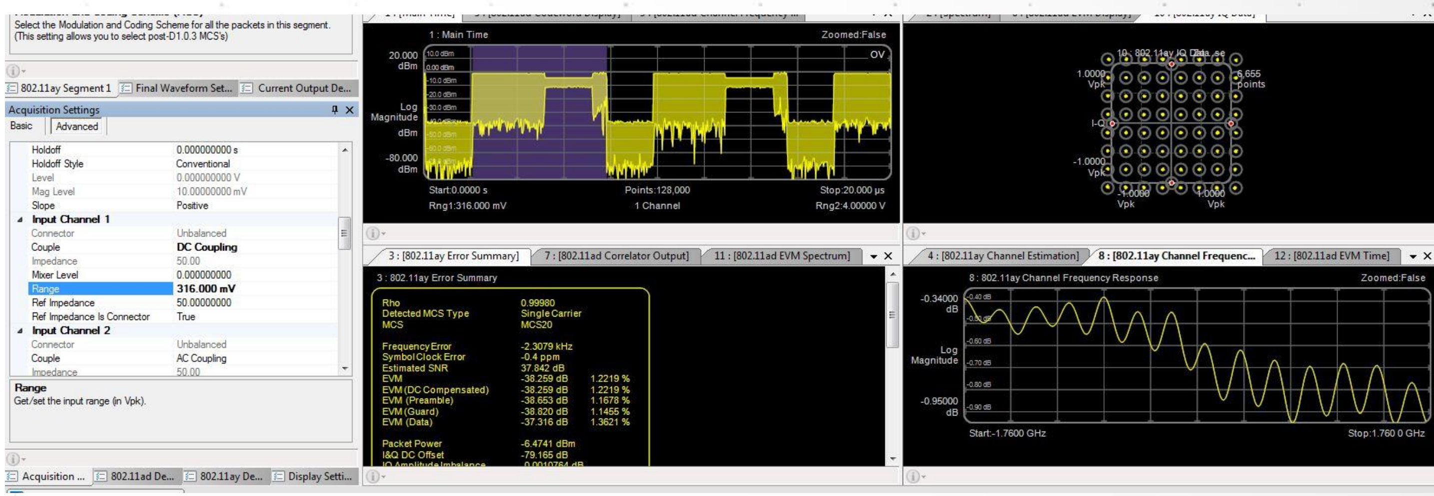


VXG (MCS 1.5) | UXR w/DDC Alpha | UXA

Industry Leading Performance

MULTI-CHANNEL, WIDE BANDWIDTH EVM LEADER





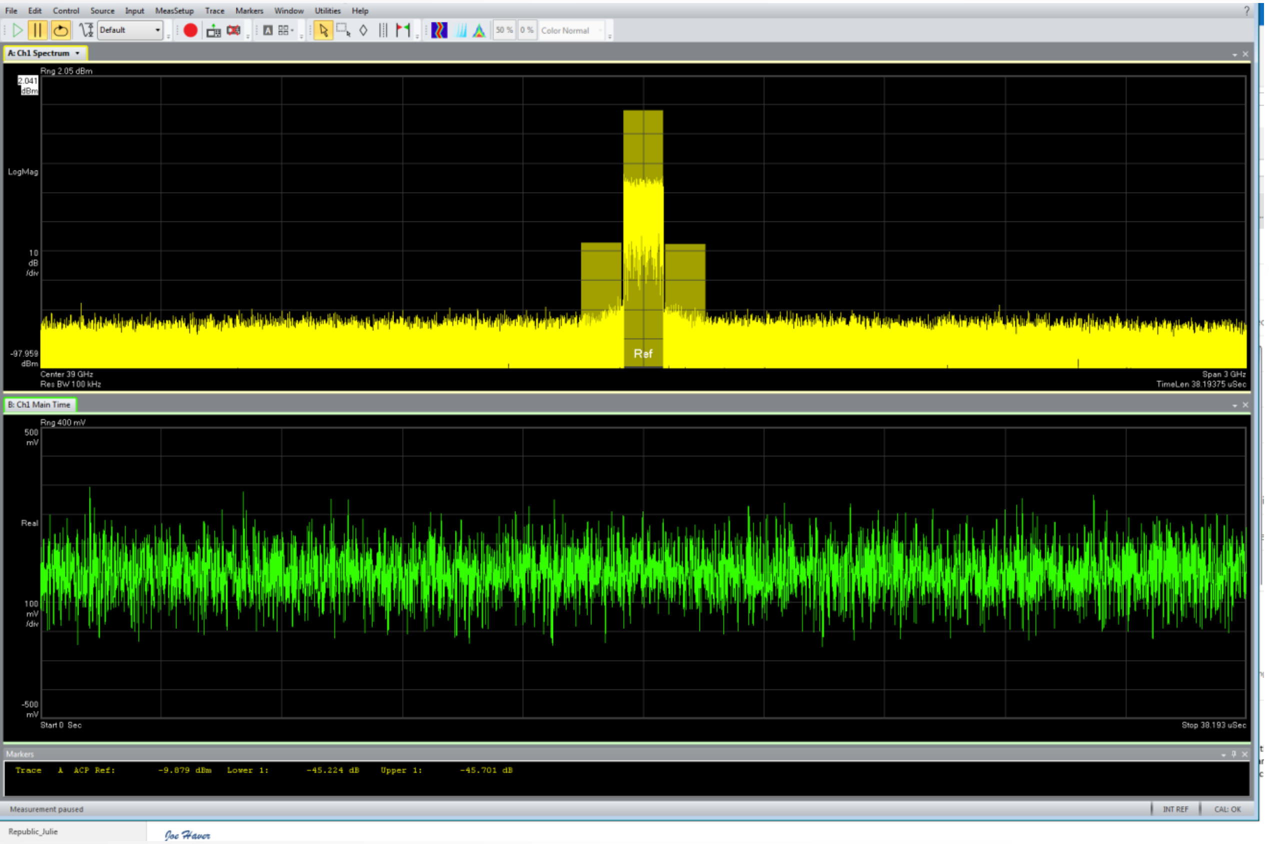
5GNR EVM*	1 Carrier -5dBm	8 Carrier -5dBm	1 Carrier -35dBm
28GHz	0.8%	1.3%	2.0%
39GHz	0.8%	1.6%	2.5%

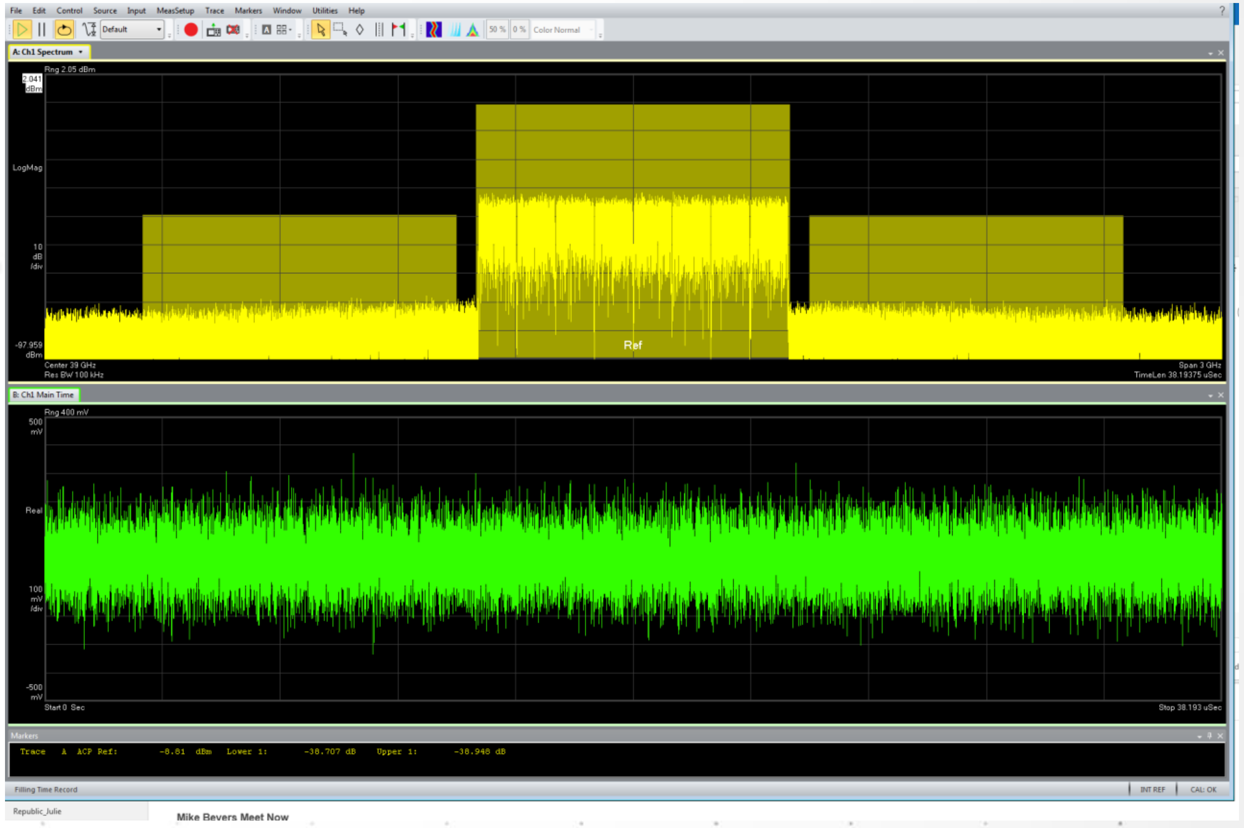
802.11 EVM*	AD MCS12.6 (2GHz)	AY MCS20 (4GHz)
61GHz	1%	1.3%

*Measured performance on one instrument.

ACPR of UXR

MCS GENERATOR, UXR LP





100MHz @ 39GHz, ACPR is -45dB
105MHz Offset

800MHz @39GHz, ACPR is -39dB
850MHz Offset

KEYSIGHT TECHNOLOGIES

Backup

KEYSIGHT TECHNOLOGIES